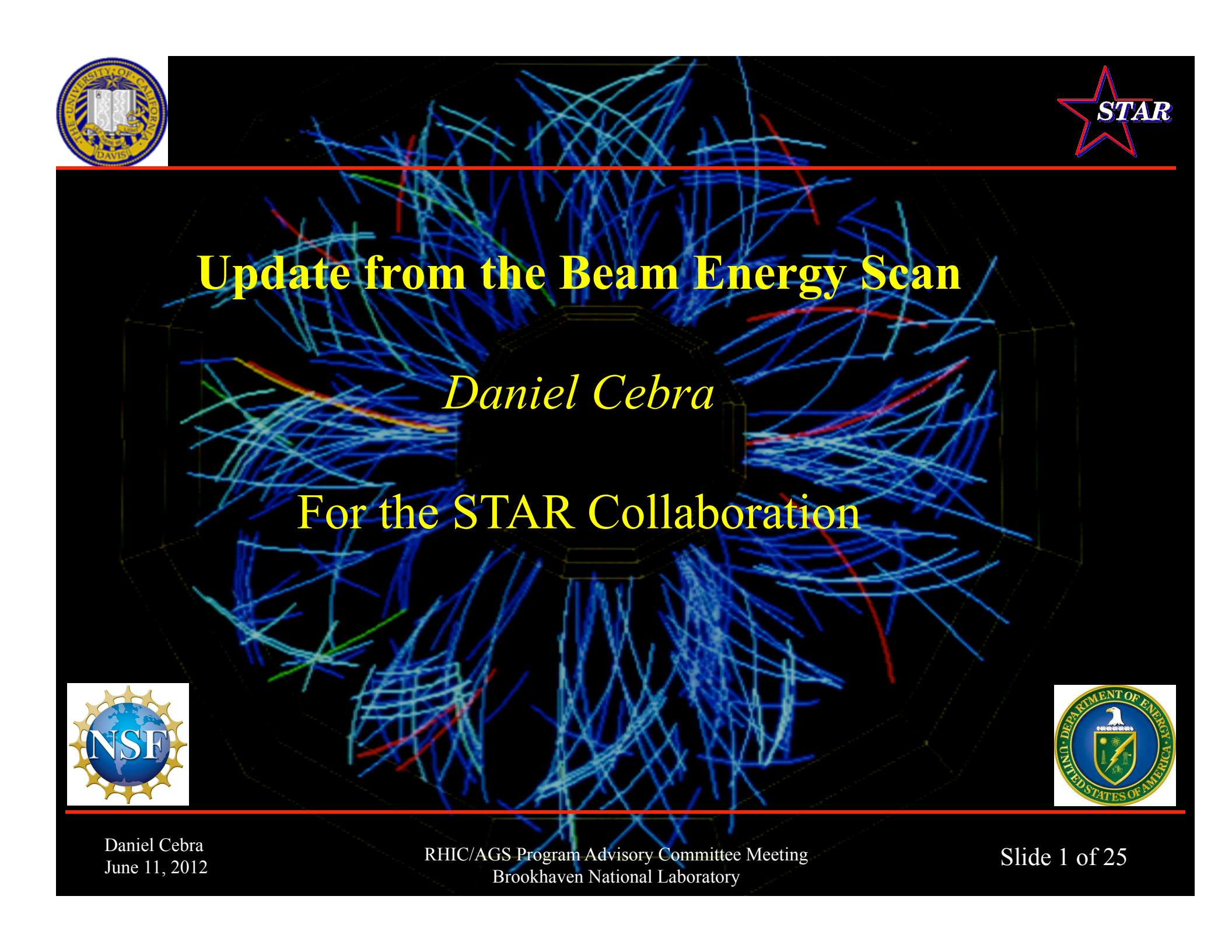


Update from the Beam Energy Scan

Daniel Cebra

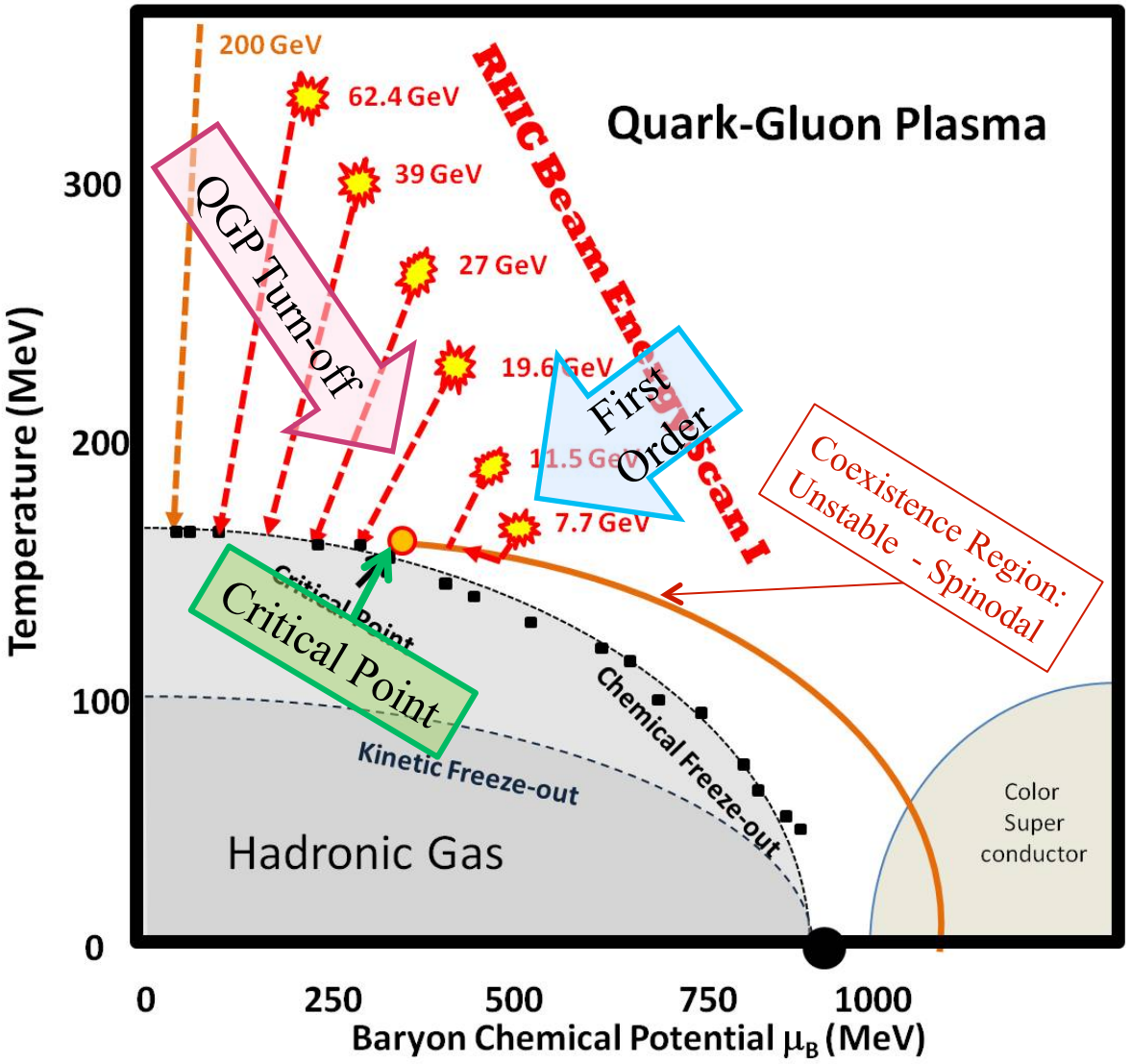
For the STAR Collaboration

The RHIC Beam Energy Scan

- Much progress has been made in understanding the phase diagram of QCD matter. We expect a cross-over at high energy. At lower energy there should be a first order transition.

- Mapping the features of the QCD matter phase diagram is key to our understanding dense matter.

- In 2009 the RHIC PAC approved a series of six energies to search for the **turn-off of QGP signatures**, the **critical point**, and evidence of a **first order phase transition**.



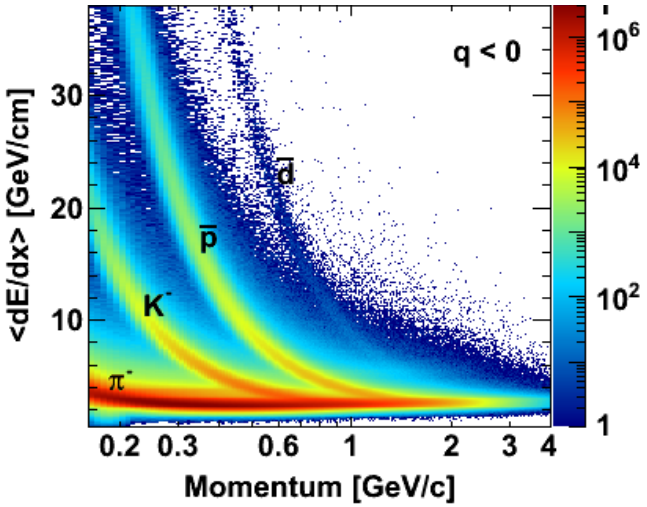
Beam Energy Scan

	Collision Energies (GeV)	5	7.7	11.5	19.6	27	39	62.4
	Chemical Potential (MeV)	**550**	**420**	**315**	**205**	**155**	**115**	**72**
	Observables	Millions of Events Needed						
QGP	n_{cq} scaling π/K/p/Λ	8.5	**6**	**5**	**5**	**4.5**	**4.5**	
QGP	R_{CP} up to p_T ~4.5, 5.5, 6.0				**15**	**33**	**24**	
QGP	Local Parity Violation		**4**	**4**	**4**	**4**	**4**	
1st Order	v_2 (up to ~1.5 GeV/c)	**0.3**	**0.2**	**0.1**	**0.1**	**0.1**	**0.1**	
1st Order	v_1	0.5	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	
1st Order	Azimuthally sensitive HBT	4	**4**	**3.5**	**3.5**	**3**	**3**	
C.P.	PID fluctuations (K/π)	1	**1**	**1**	**1**	**1**	**1**	
C.P.	net-proton kurtosis	5	**5**	**5**	**5**	**5**	**5**	
	Total Number of *Good* Events Taken (Millions)	0	**4.3**	**11.7**	**36**	**70**	**130**	**67**

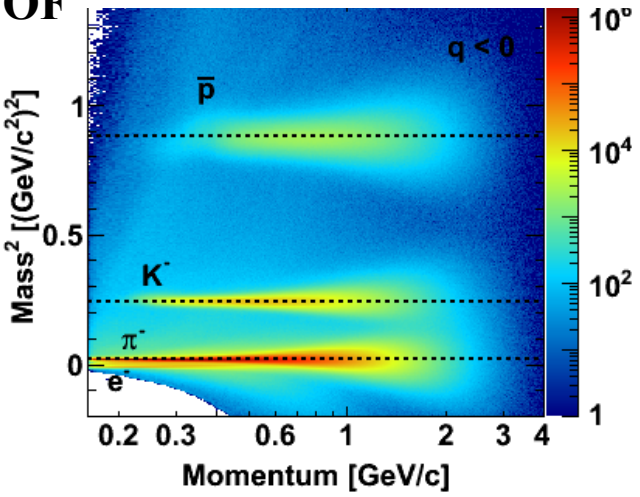
Setting the Scene

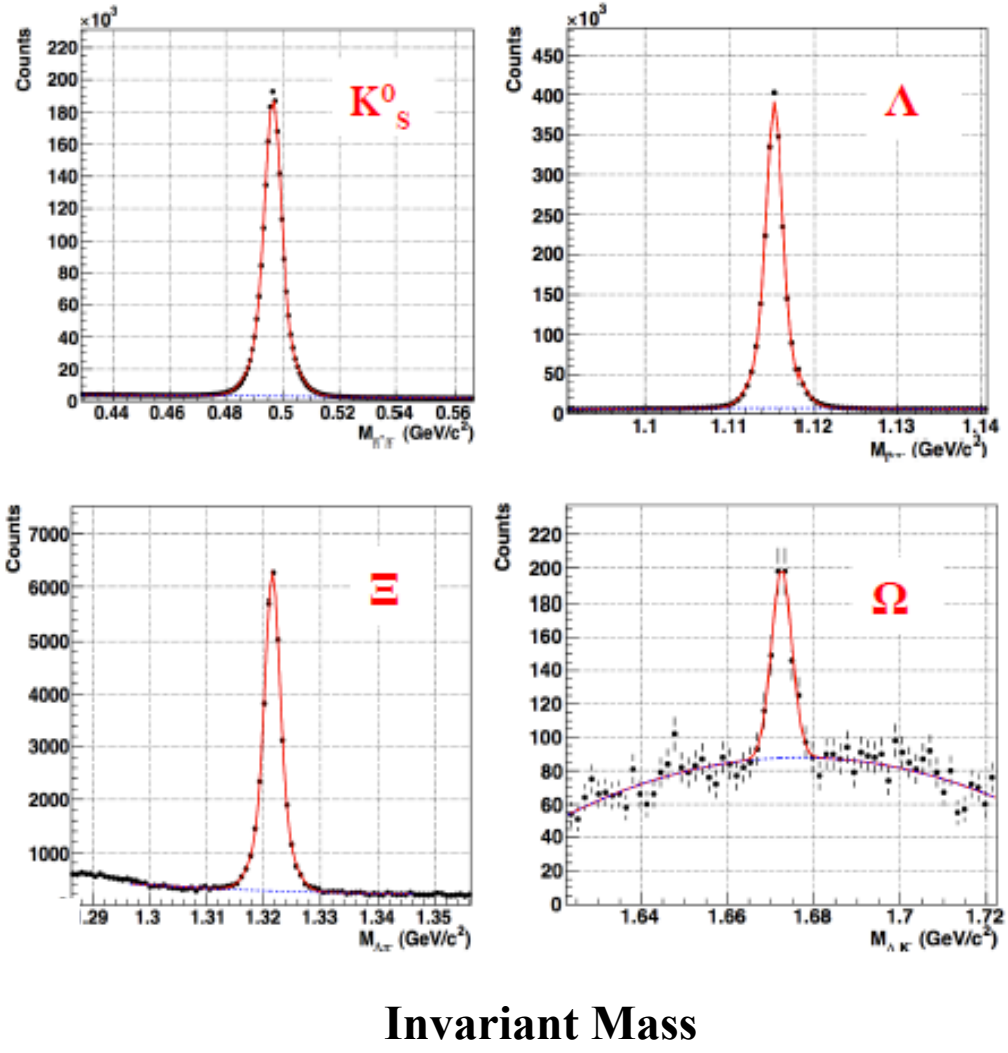
Particle Identification

dE/dx



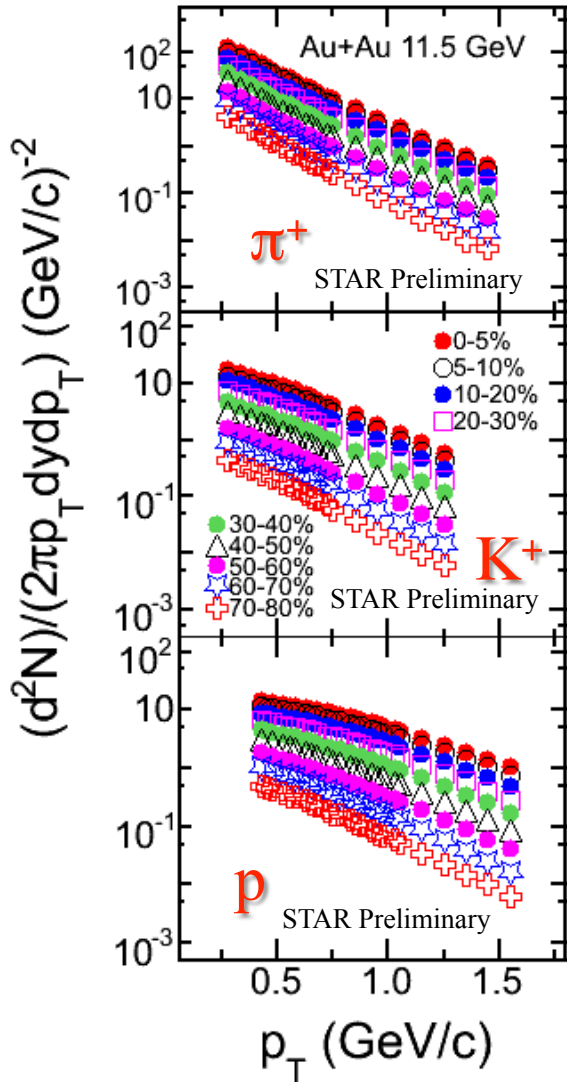
TOF

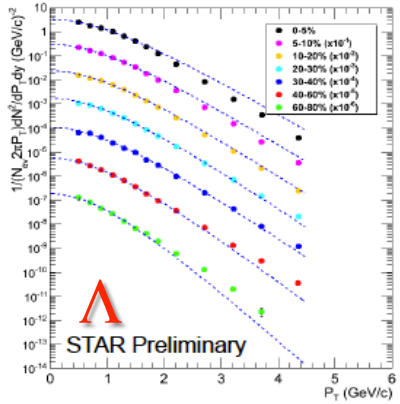


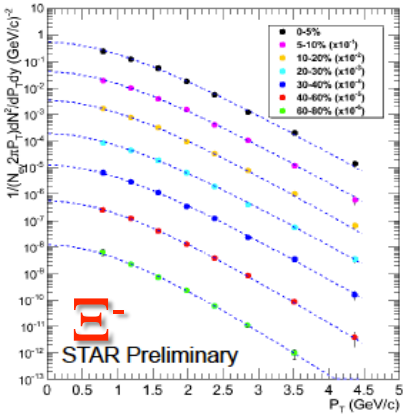


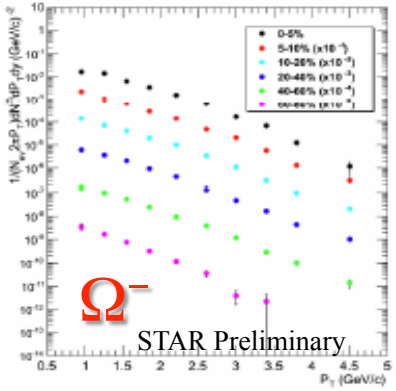
Invariant Mass

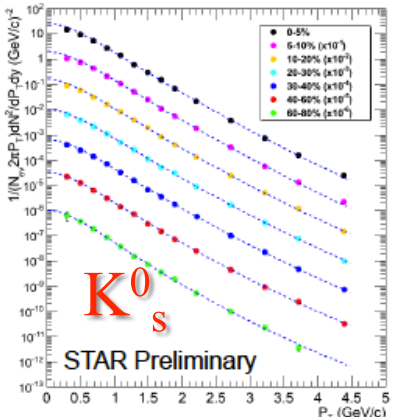
Hadron Spectra

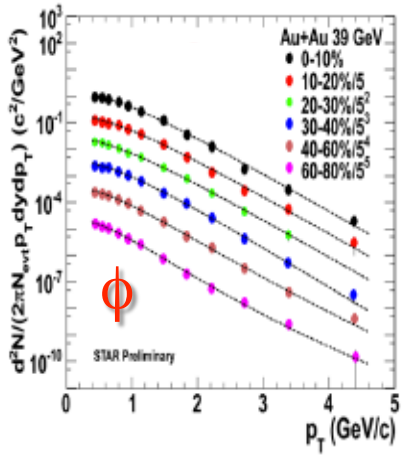








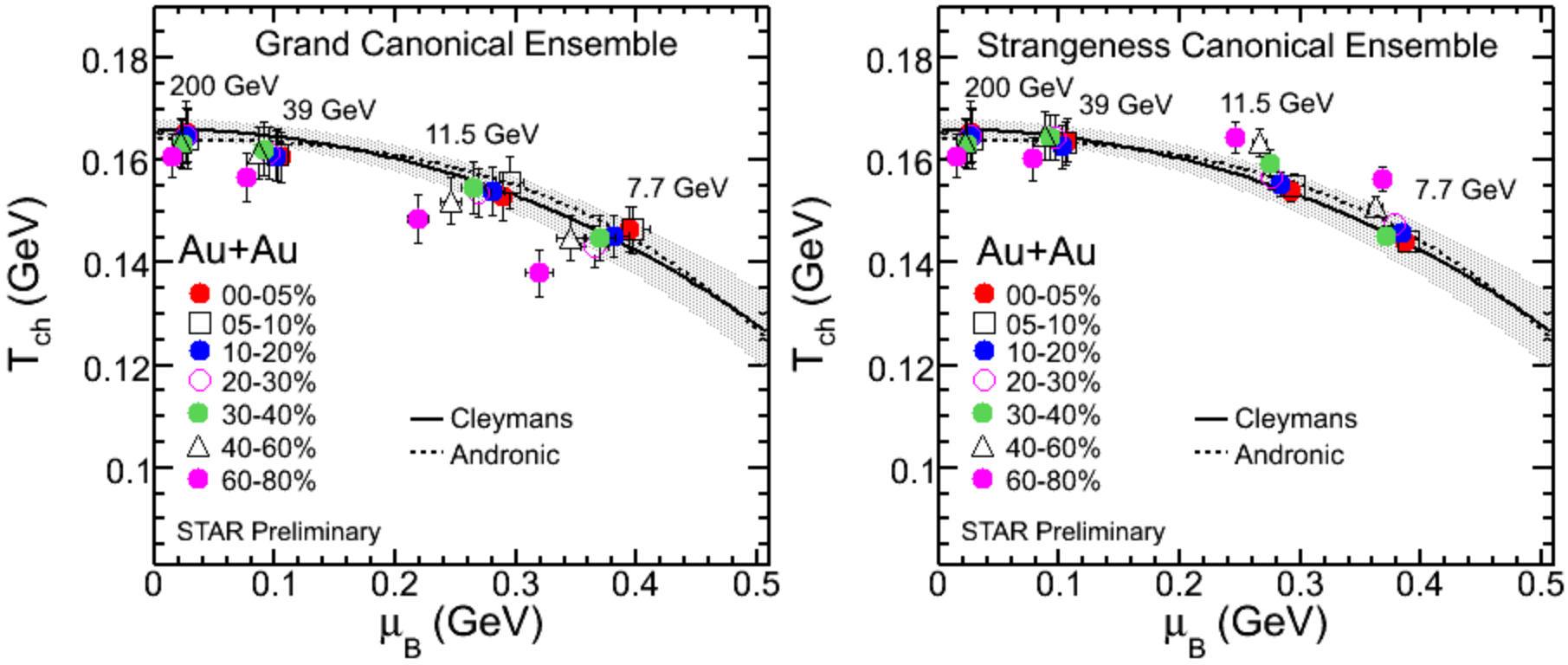




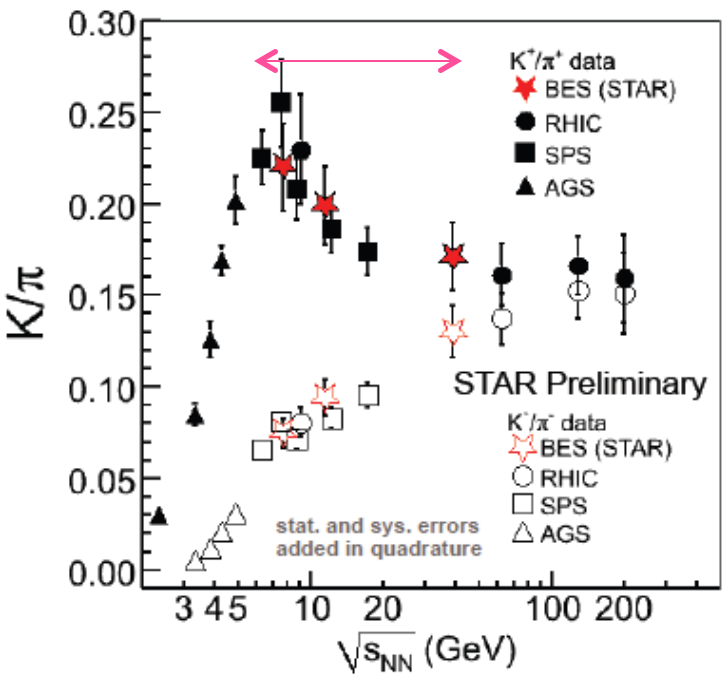
ϕ, K^0_s : Levy function fits
Λ, Ξ: Boltzmann fits
Λ: feed-down corrected

Chemical Equilibrium

Adding the strange particle ratios to the π, K, and p and using different ensembles in the thermal model, we can study the centrality and energy dependence of T and μ_B



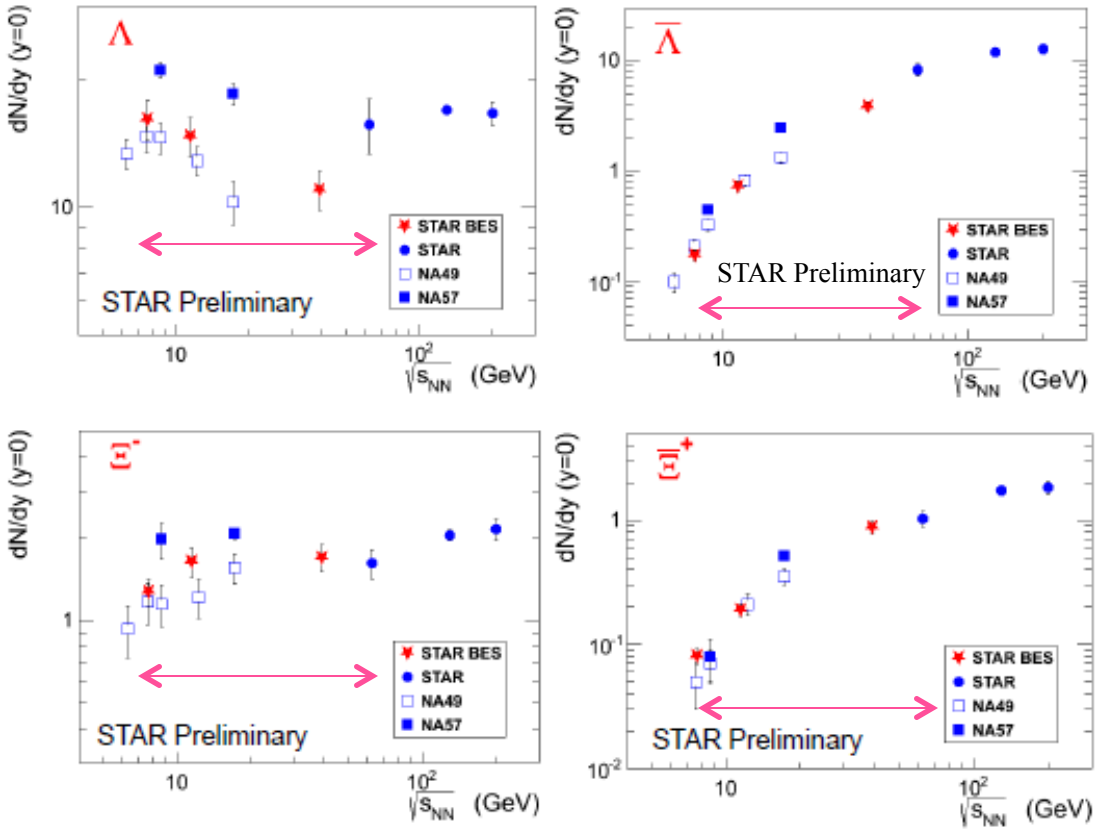
The Horn and Other Yields



STAR Ref.: B. I. Abelev et al., PRC79 (2009) 034909
B. I. Abelev et al., PRC81 (2010) 024911

E802 Ref.: L. Ahle et al., PRC58 (1998) 3523
L. Ahle et al., PRC80 (1999) 044904
E895 Ref.: J. L. Klay et al., PRC68 (2003) 054905
E877 Ref.: J. Barrette et al., PRC62 (2000) 024901

NA49 Ref.: S. V. Afanasiev et al., PRC66 (2002) 054902
C. Alt et al., PRC77 (2008) 024903



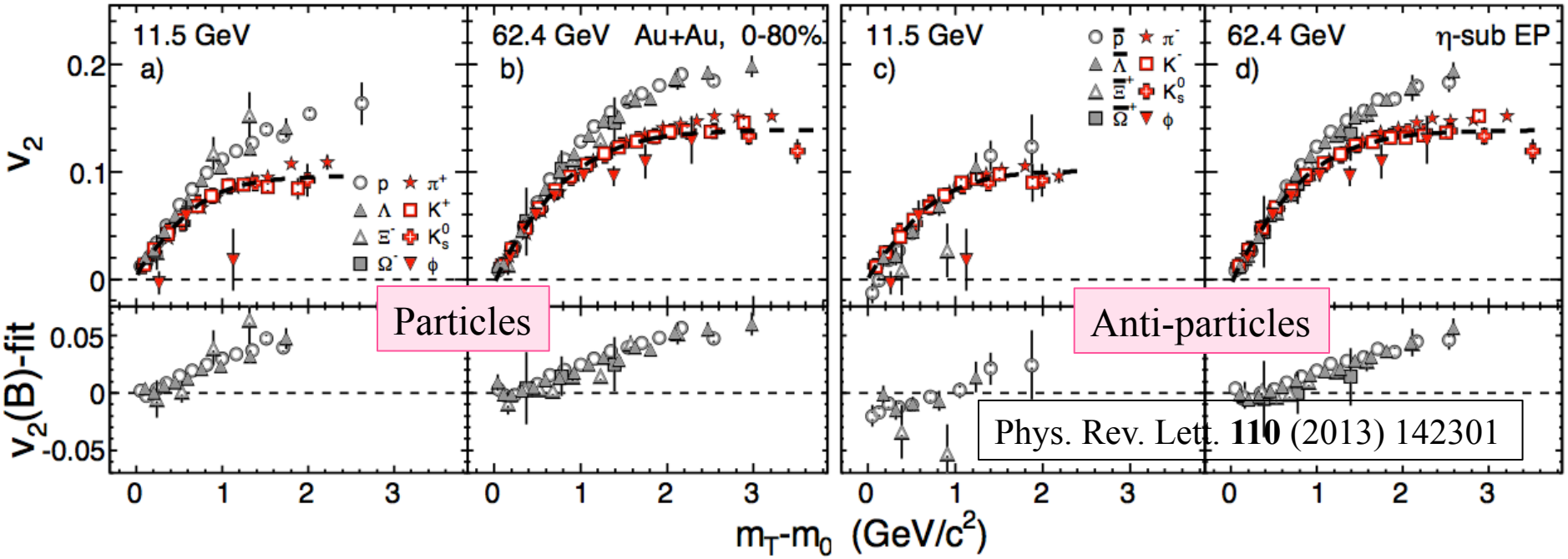
The STAR BES data are consistent with the NA49 results

NA49, PRC78,034918.
NA57, PLB595,68; JPG32, 427
STAR, PRL86,89,92,98;PRC83

Turn-off of QGP Signatures

Constituent Quark Scaling – BES Results

scaling by the number of quarks ➔ partonic collectivity➔deconfinement
Baryon/meson and high m_t-m_0 indicates NCQ scaling



Phys. Rev. Lett. **110** (2013) 142301

Particles:
- Baryon/Meson splitting at 11.5 GeV
- No baryon/meson splitting at 7.7 GeV
- QGP Signature turned off

Anti-Particles:
- No baryon/meson splitting at 11.5 GeV
- QGP Signature turned off

Constituent Quark Scaling – BES Results

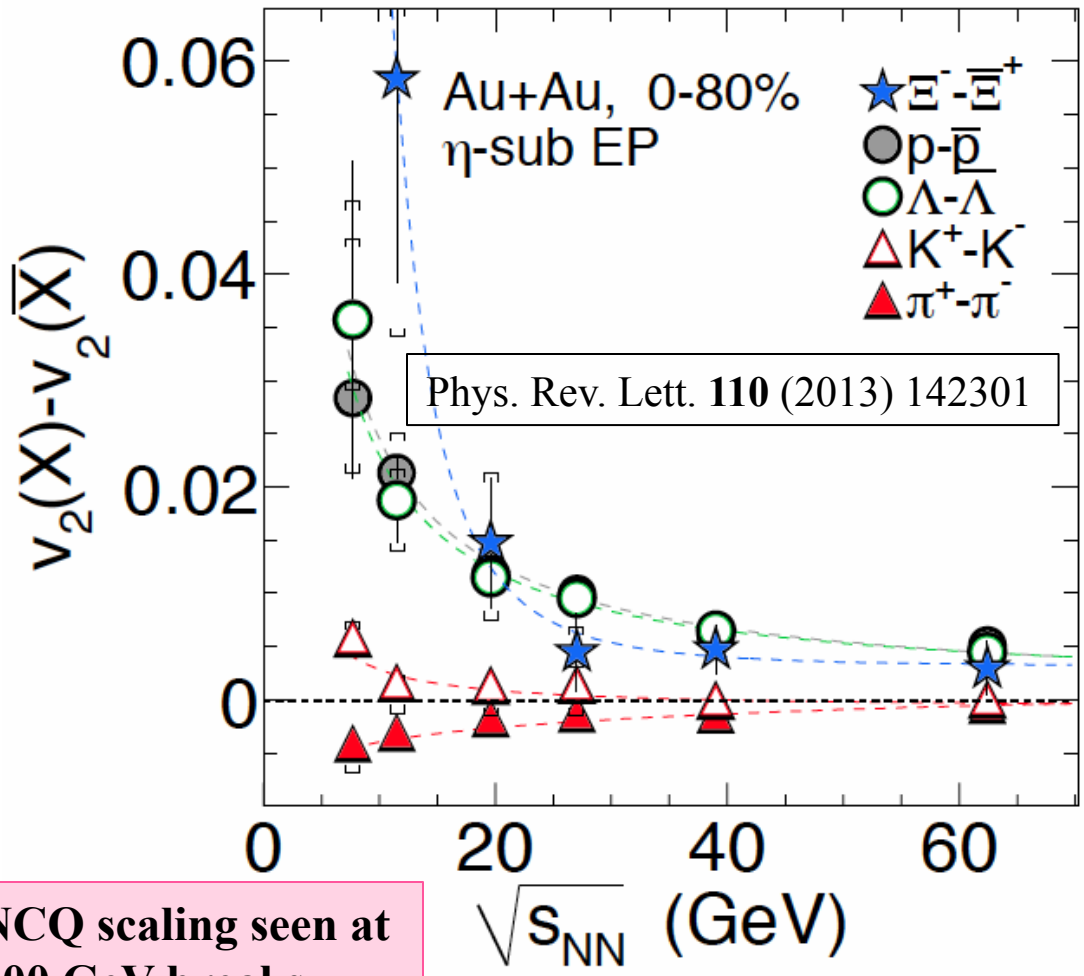
- **There is a remarkable difference between particles and their anti-particles, especially for the lowest energies in the range.**

- **Difference between particles and their anti-particle decreases with increasing beam energy.**

- **Most significant below 19.6 GeV**

Possible explanation

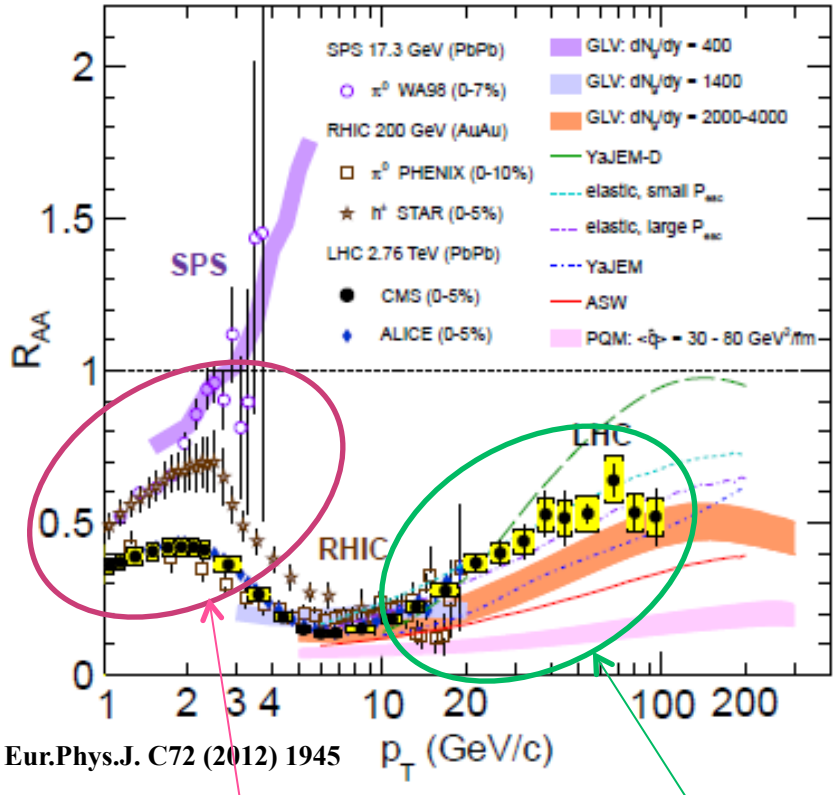
- **Baryon transport to mid-rapidity** [J. Dunlop et al., PRC 84, 044914 (2011)]
- **Hadronic potential** [J. Xu et al., PRC 85, 041901 (2012)]



NCQ scaling seen at 200 GeV breaks down at lower energies

Turn-off of QGP Signatures

High p_T suppression has been seen as a clear manifestation of energy loss by color objects (quarks) in a color medium (QGP)



Eur.Phys.J. C72 (2012) 1945

Thermal emission from a radial expanding source or Cronin Effect

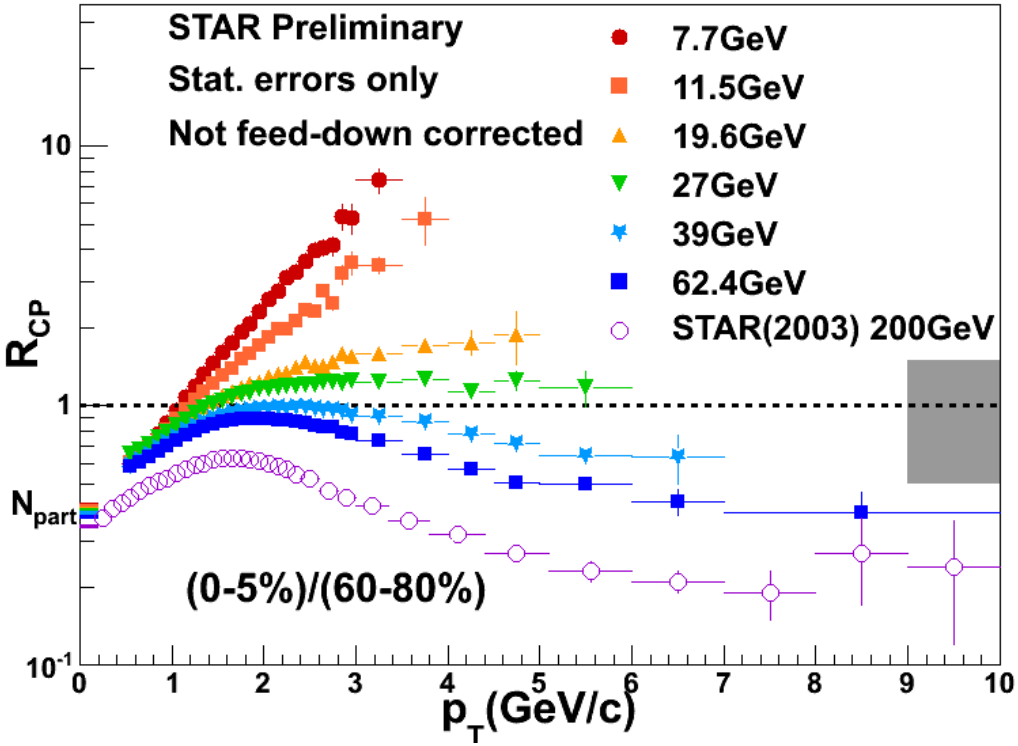
Perturbative QCD and parton energy loss

- R_{cp} suppression NOT seen at lower energies!

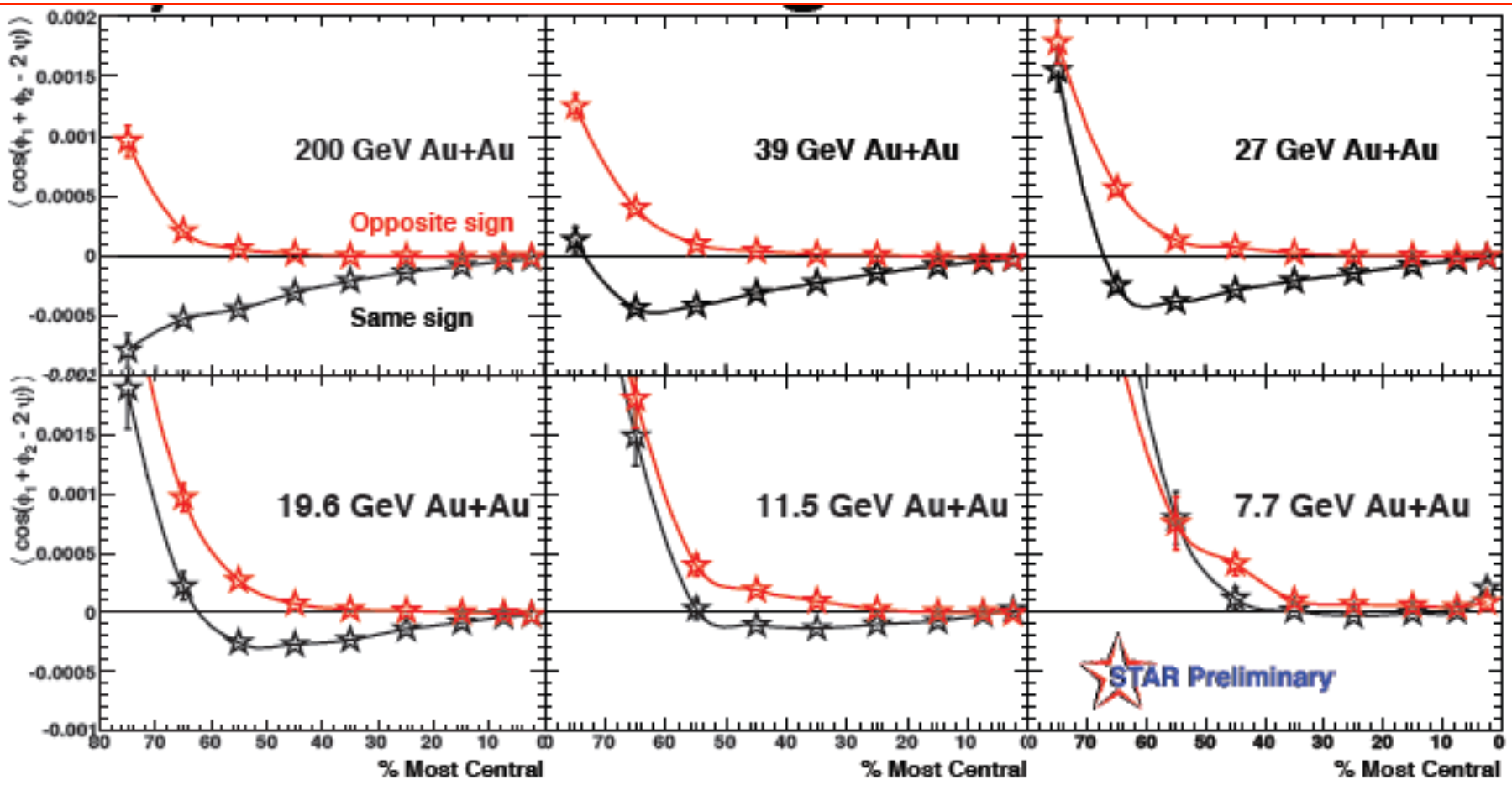
➔**The QGP *signature* is turned off.**

➔**Is QGP turned off?**

➔ **Need p+A in this energy range.**



Local Parity Violation – BES Results

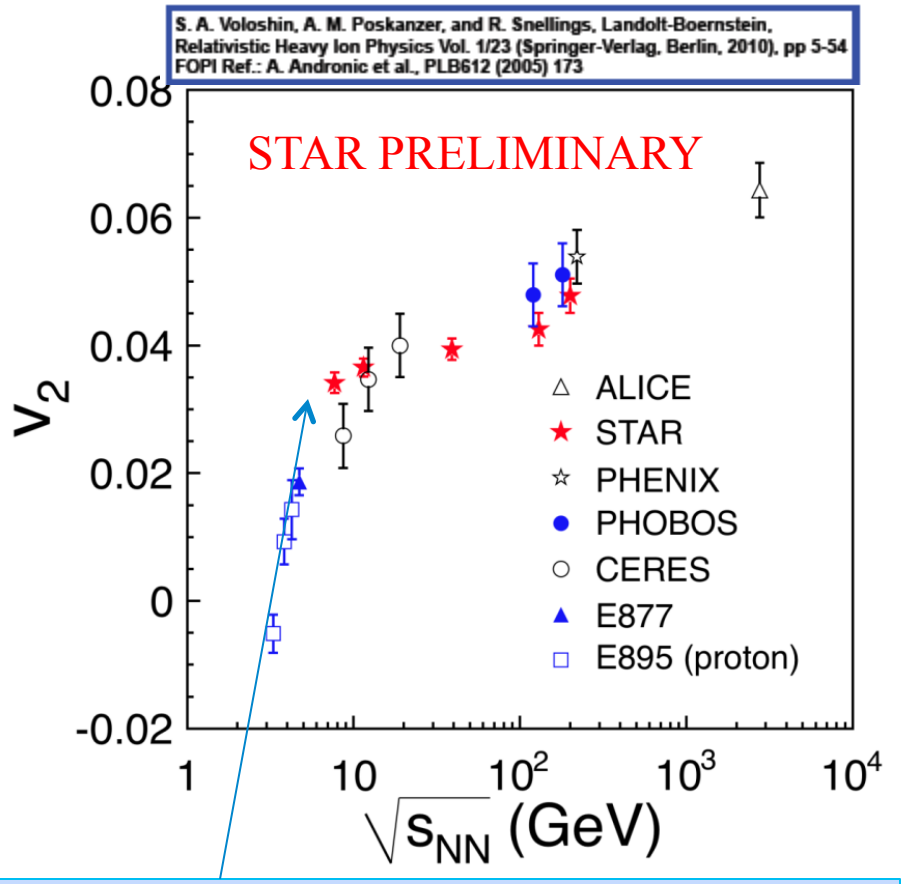


The anisotropy attributed to the Chiral Magnetic Effect is gone at 7.7 GeV

Search for 1st Order PhaseTransition

Elliptic Flow – BES Results

A reduction in flow or in the rate of increase in flow could indicate a softening of the equation of state.



Many caveats with this comparison:

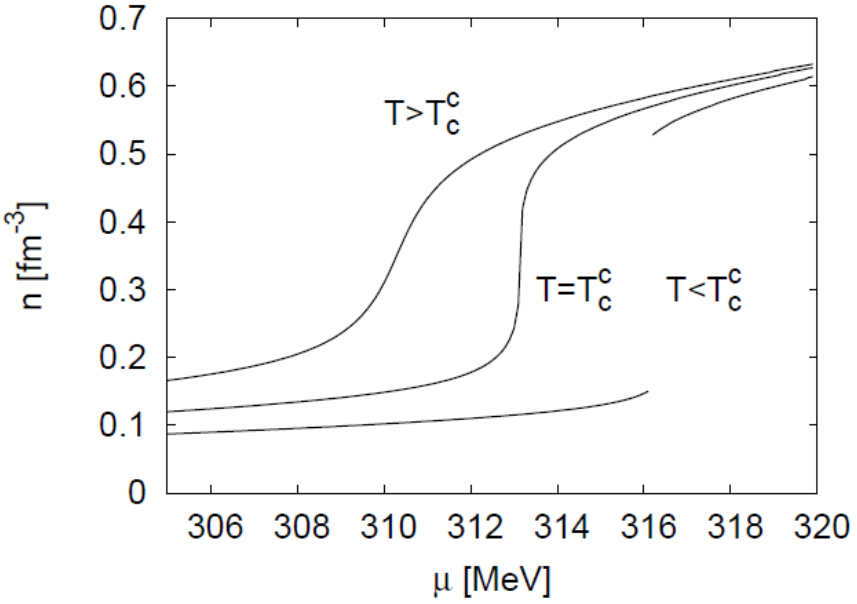
- We need v_2 of indentified particles
- We need consistent analysis methods between energy ranges
- Such detailed analyses are not available in the previous published results

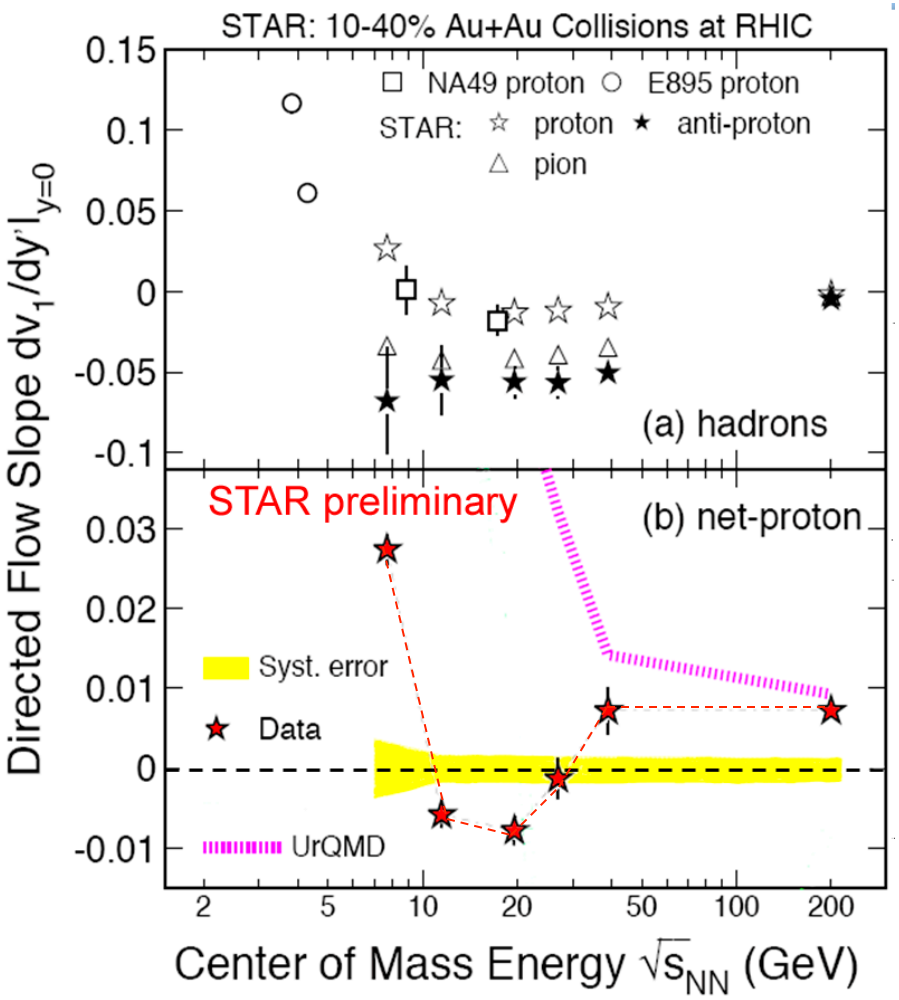
➔ This rough comparison highlights the **need for STAR data below 7.7 GeV**

- Elliptic Flow is rising rapidly with beam energy at AGS energies
- The rate of increase is reduced above 7.7 GeV for BES energies

Directed Flow -- BES

B. Schaefer and J. Wambach Phys.Rev. D75 (2007) 085015





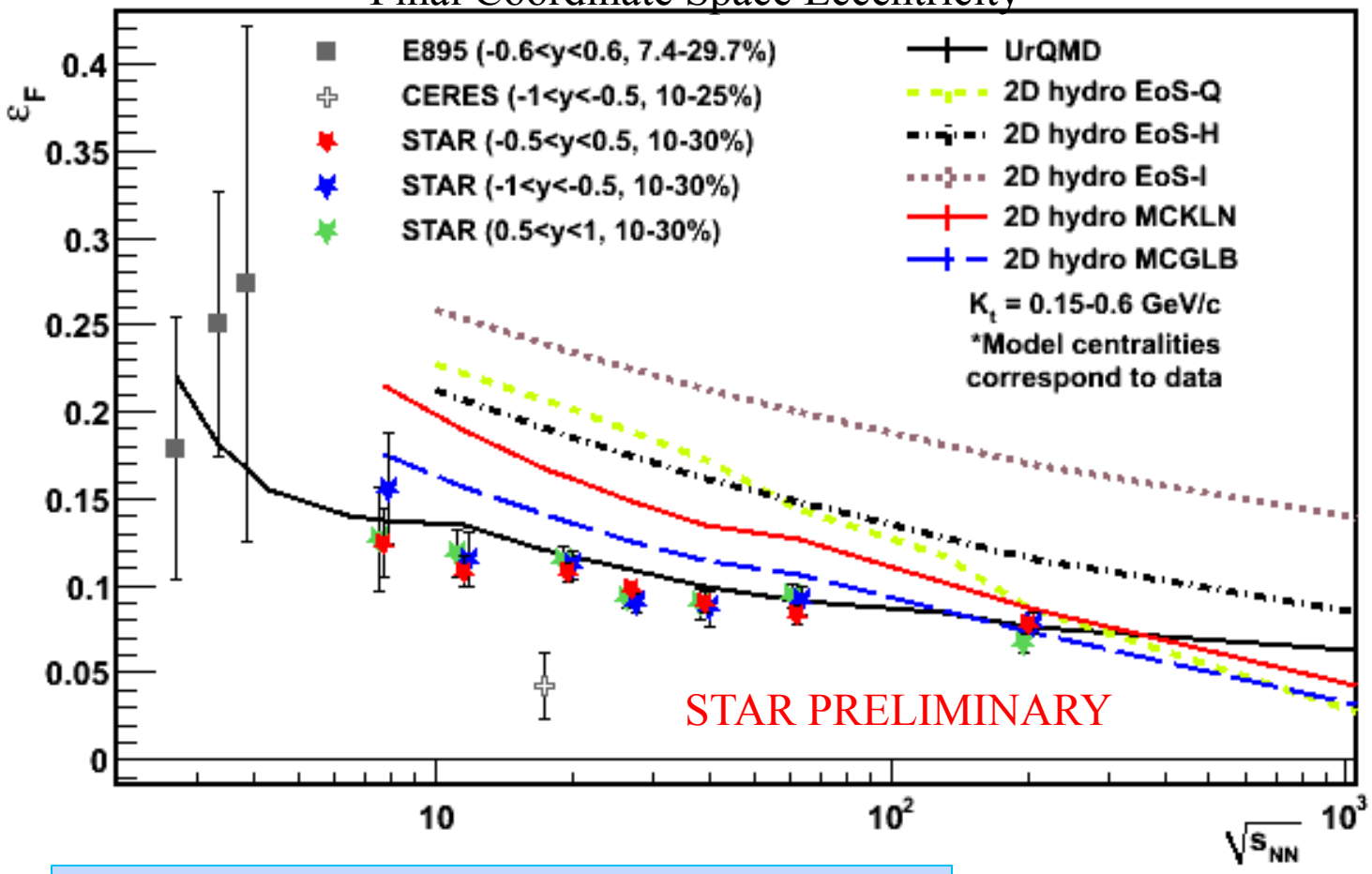
- Lattice QCD calculations predict a first order phase transition seen, as a discontinuity in the density.
- First order phase transition is characterized by unstable coexistence region. This spinodal region will have the lowest compressibility
- v_1 is a manifestation of early pressure in the system
- We see a minimum of the v_1 signal between 11.5 and 19.6 GeV ➔ **New data are needed at 15 GeV**

Azimuthally Sensitive HBT - BES Results

- Initial eccentricity defined by overlap.
- A softening of the equation of state would change the spatial expansion of the system.
- This would be seen in ε_F.

- Checked suggestive CERES result
- The expansion (reduction of ε_F) slows above 7.7 GeV.
- No minimum in ε_F is observed.

Final Coordinate Space Eccentricity



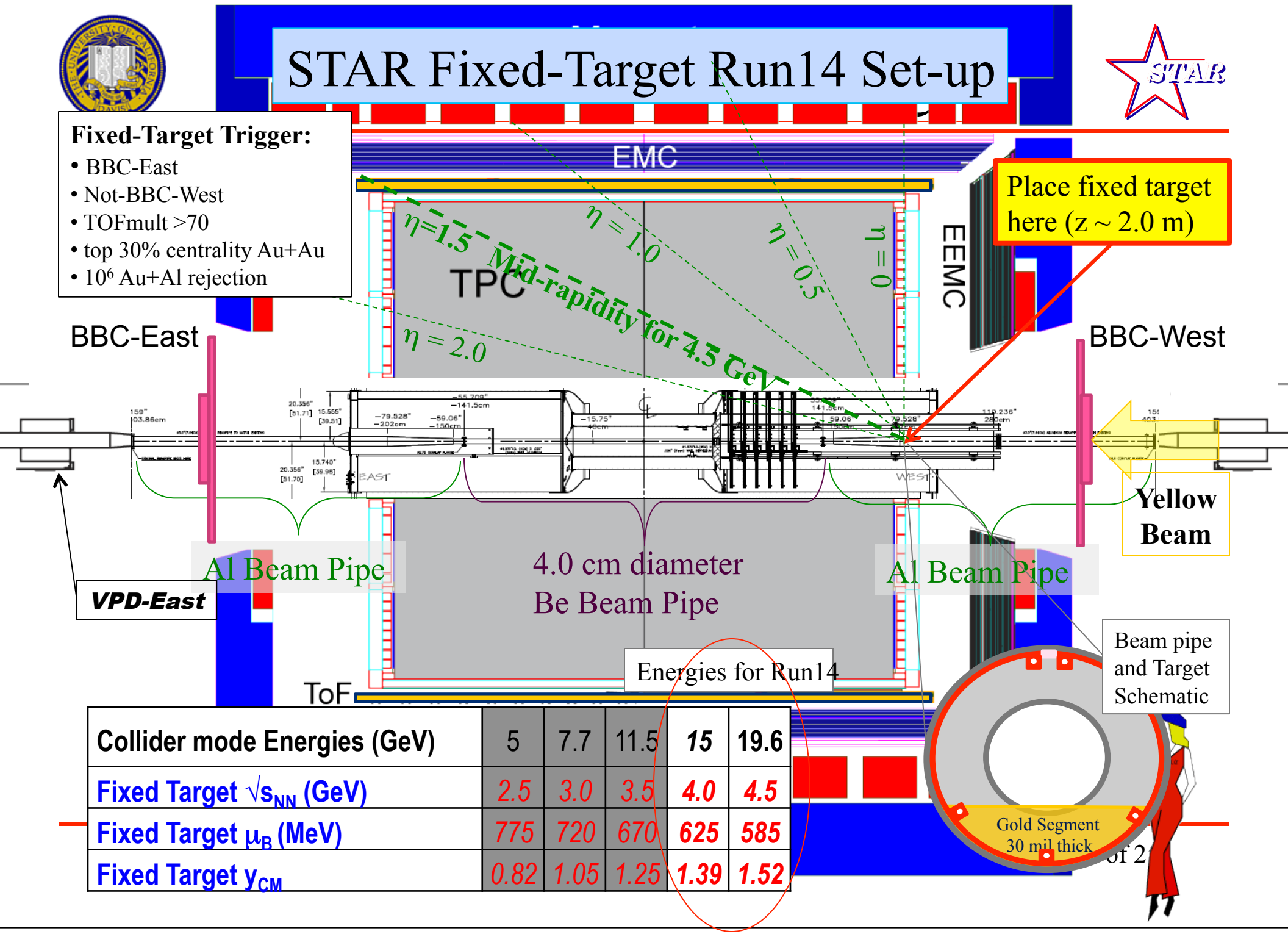
The E895 data are inconclusive
➔ **STAR data below 7.7 GeV are needed**

Search for 1st Order P.T. below 7.7 GeV

➔ Fixed-Target

STAR Fixed-Target Run14 Set-up

Fixed-Target Trigger:
- BBC-East
- Not-BBC-West
- TOFmult >70
- top 30% centrality Au+Au
- 10^6 Au+Al rejection

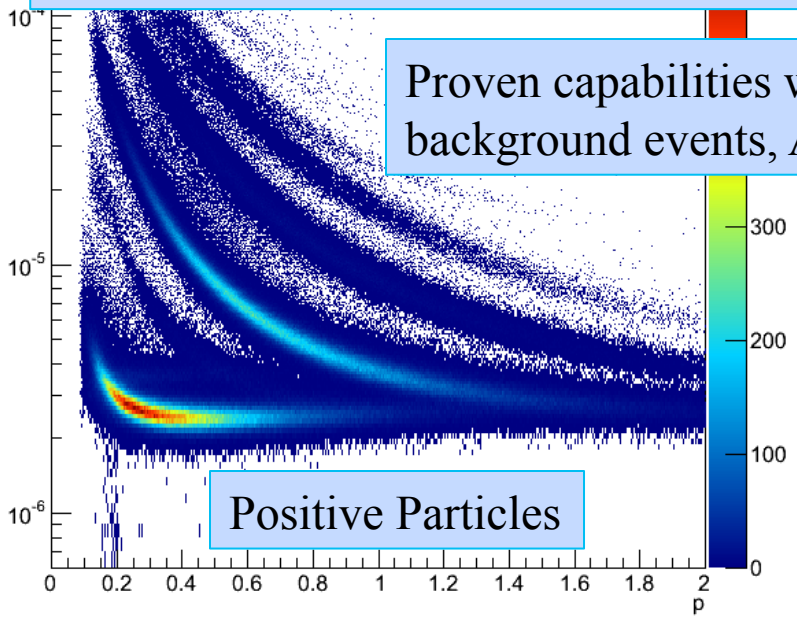


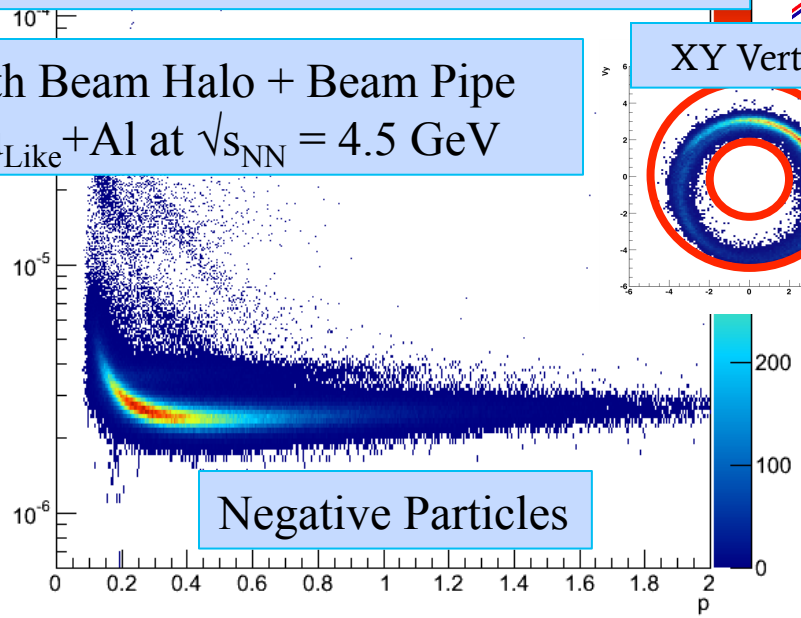
Energies for Run14

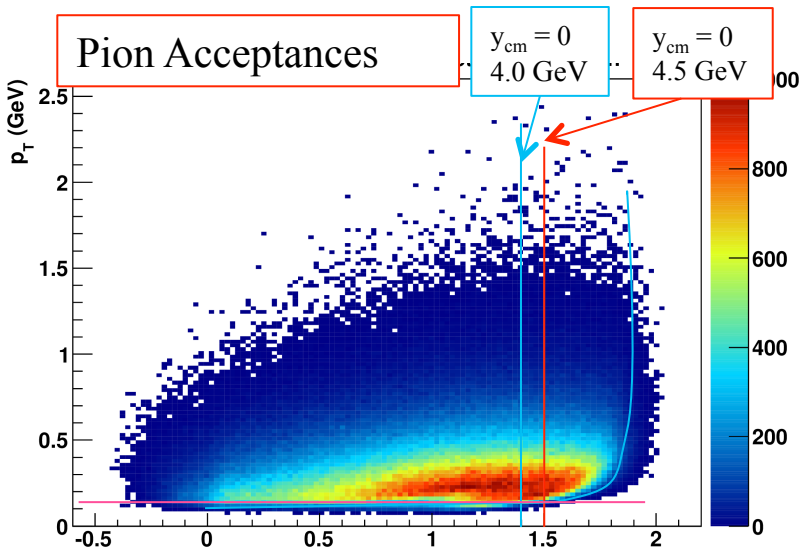
Collider mode Energies (GeV)	5	7.7	11.5	15	19.6
Fixed Target $\sqrt{s_{NN}}$ (GeV)	2.5	3.0	3.5	4.0	4.5
Fixed Target μ_B (MeV)	775	720	670	625	585
Fixed Target y_{CM}	0.82	1.05	1.25	1.39	1.52

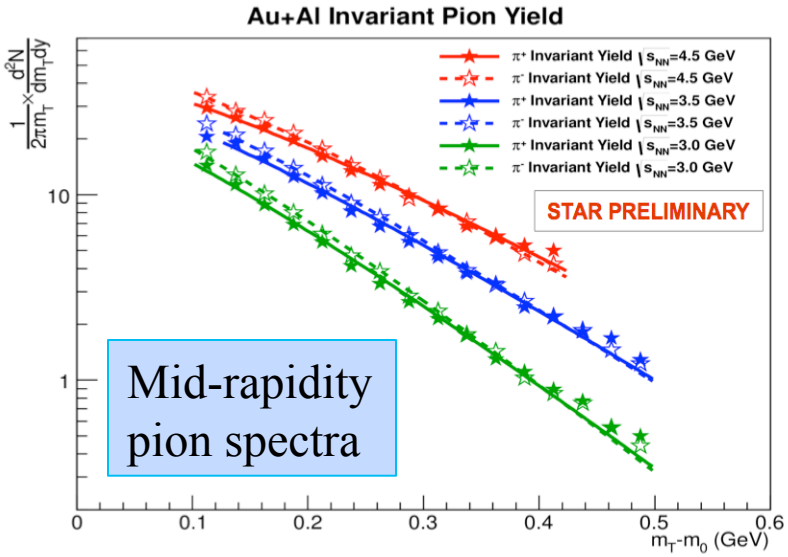
Pion Fixed-Target PID, Acceptance, Spectra

Proven capabilities with Beam Halo + Beam Pipe background events, Au_{Like}+Al at $\sqrt{s_{NN}}$ = 4.5 GeV









STAR Fixed-Target Run14 Goals

•All Au_{Like}+Al data taken during BES were pile-up background events
➔We need to develop a dedicated fixed-target trigger, however the test run request becomes irrelevant if RHIC runs 15GeV Au+Au before running 200 GeV Au+Au.

•It is likely/possible that in the beam halo events studied in the BES data sets the projectile nucleus is a heavy projectile fragment from an upstream beam-gas nuclear interaction
➔We request a test to intentionally steer the beams to graze the target to create known Au+Au events.

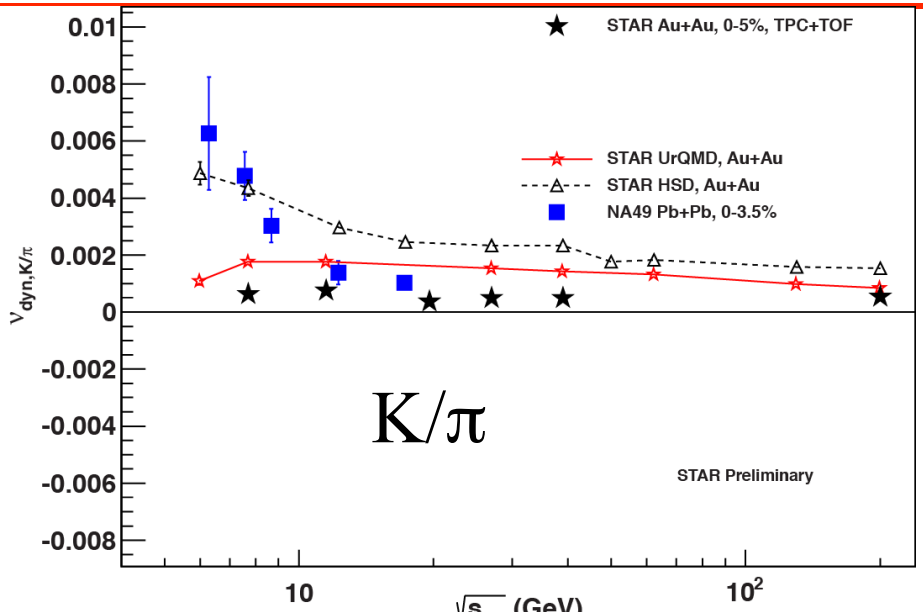
➔ **We will need the target to be designed, fabricated, and installed during this summer shutdown.**

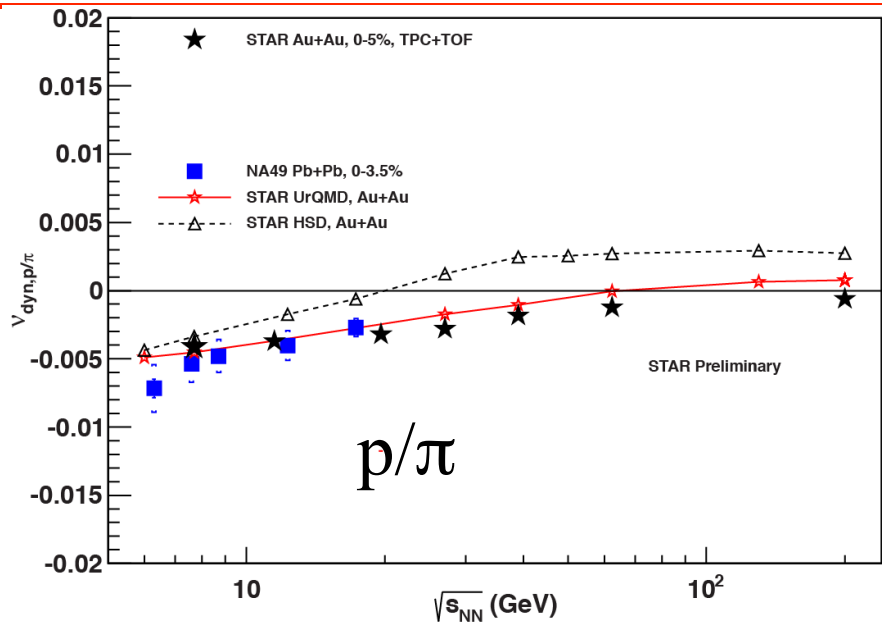
Physics goals for Run14 Au+Au at 4.0 GeV:
- Elliptic flow of identified π^+, π^-, and p
- Directed flow of protons
- Azimuthally sensitive HBT of pions

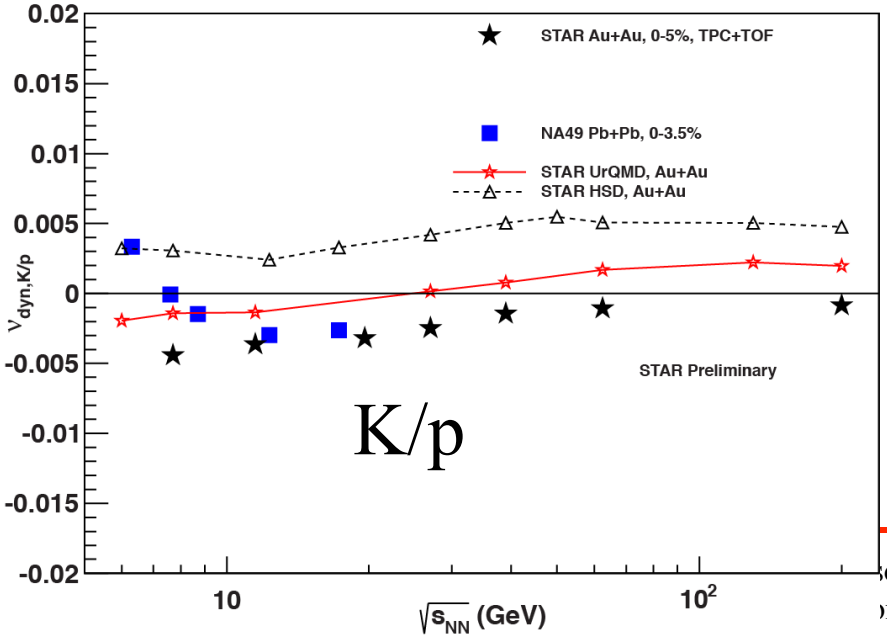
} These are out key 1st Order Phase Transition signatures

Search for the Critical Point

Ratio Fluctuations – BES Result







- Naively, fluctuations are expected at the critical point
- STAR data show no significant energy dependence for K/π fluctuations
- Smooth evolution with energy for p/π and K/p fluctuations
- No non-monotonic behavior is observed

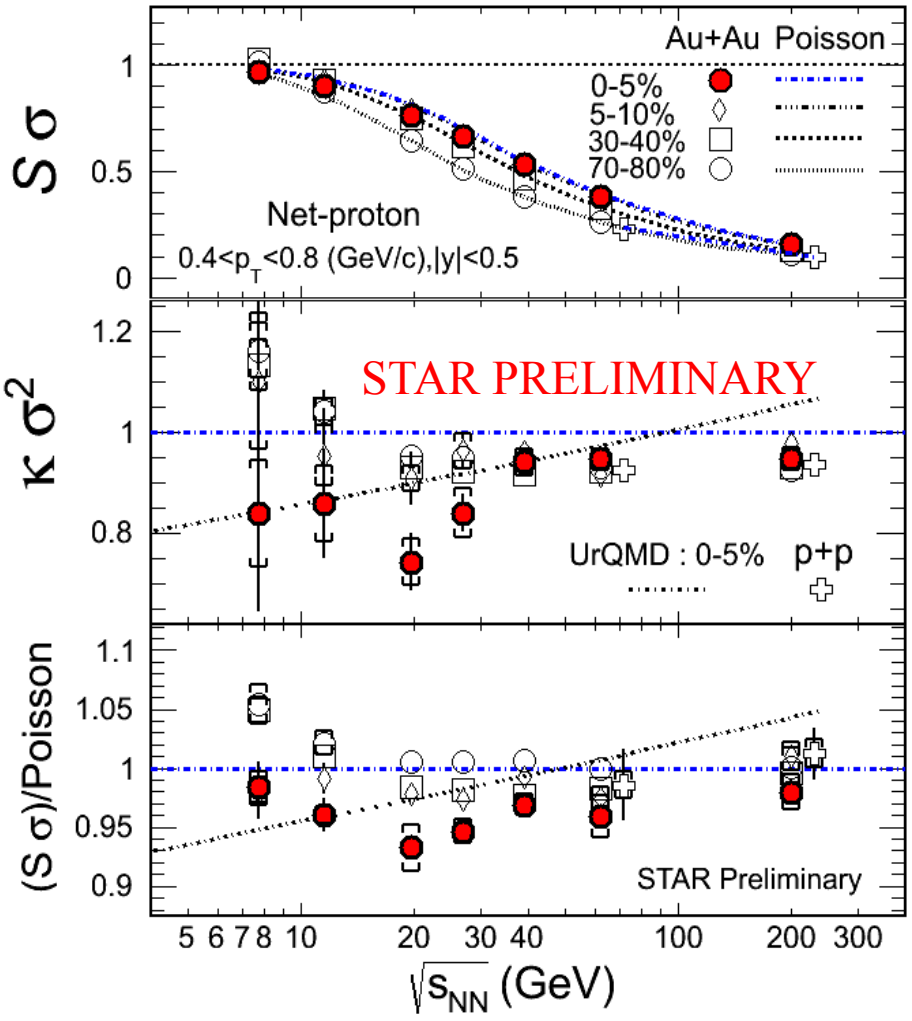
➔ **We need a more sensitive observable**

Higher Moments – Net Proton Skew/Kurtosis - BES

• Third (Skew) and Fourth (Kurtosis) moments are increasingly sensitive to fluctuations expected at a critical point.
• Ratios of cumulants allow volume terms to cancel

• STAR data are similar to Poisson baseline at energies above 27 GeV.
• Deviations are seen at low energies.
• Signal size will be affected by finite size
• The gap between 11.5 and 19.6 is large, might miss the critical point
➔ **Need data at 15 GeV**

Additionally
➔ **Need detailed theory with finite systems**
➔ **More data are needed ➔ BESII**



Conclusions

1. **Turn-off of QGP signatures:**
   - NCQ scaling breaks down below 19.6 GeV
   - High p_t suppression not seen below 19.6 GeV
   - LPV effect not seen below 11.5 GeV

   ➔ **The onset of deconfinement is below 11.5 Gev**

2. **Evidence of the first order phase transition.**
   - Inflection in v_2 at 7.7 GeV
   - v_1 slope (dv_1/dy) double sign change, minimum near 15 GeV
   - Azimuthal HBT interpretation is challenging

   ➔ **Need more data near 15 GeV and below 7.7 GeV**

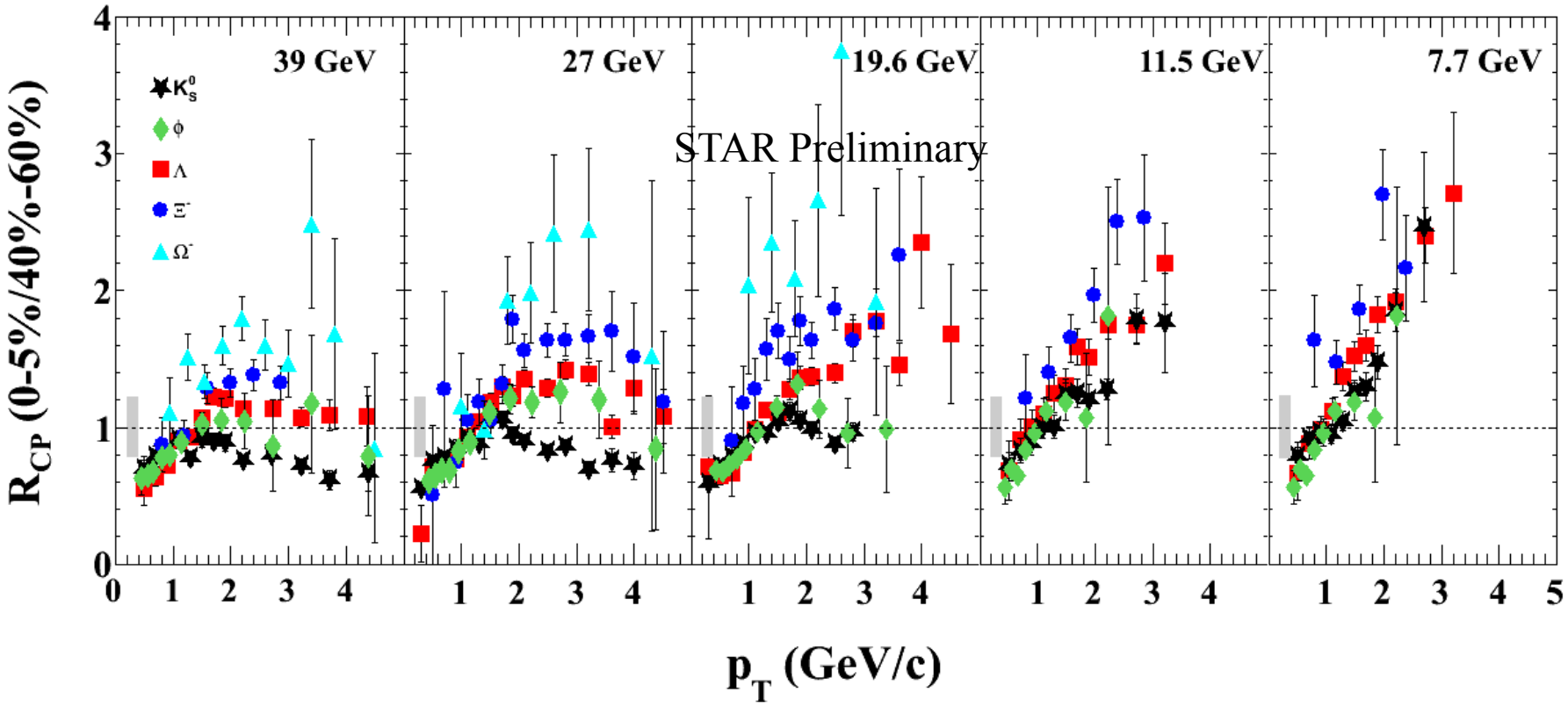
3. **Search for the critical point.**
   - Measurements of K/π, K/p, or p/π fluctuations
   - Measurements of Higher moments of the net-proton and charge

   ➔ **An Beam Energy Scan survey point is needed at 15 GeV**

   ➔ **These are challenging analyses, more data/theory ➔ BESII**

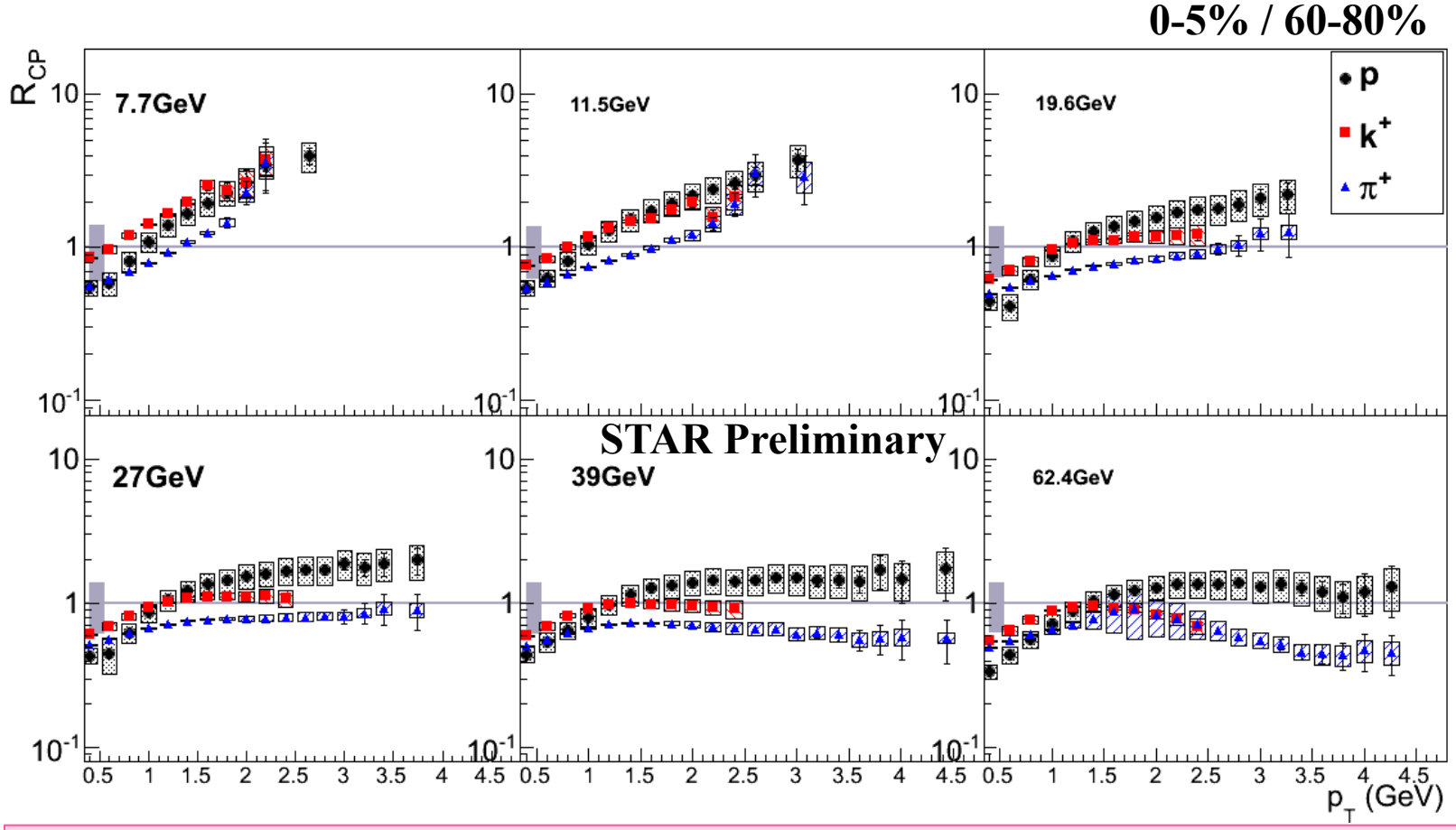
Backup

High p_T Suppression: BES Results



- R_{CP} of strange particles at 39 and 27 GeV show a similar trend as that in higher energies.
- 19.6 shows intermediate behavior
- At 11.5 and 7.7 GeV, all particles R_{CP} are larger than 1 at intermediate p_T.

High p_T Suppression: BES Results



- High p_T suppression seen at 27 GeV and above
- 19.6 shows intermediate behavior
- At 11.5 and 7.7 GeV, all particles R_{CP} are larger than 1 at intermediate p_T.

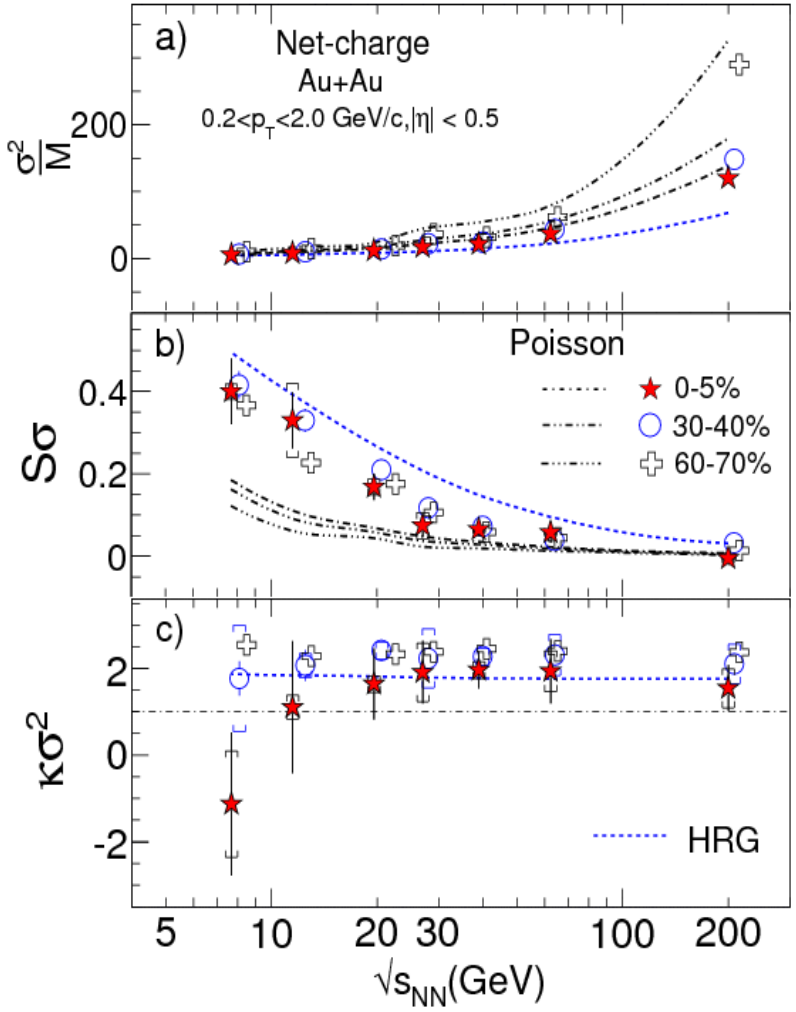
E. Sangaline QM2012

Higher Moments – Net Charge Skew/Kurtosis - BES

- Data are consistent Poisson baseline at highest energy.
- Deviations from Poisson at low energy.

➔ **More theory is needed**

➔ **More data are needed**



Draft paper in God Parent Committee